DESY 95-130
July 1995

On dynamical parton distributions of hadrons and photons*

Andreas Vogt♯

Deutsches Elektronen-Synchrotron DESY
Notkestraße 85, D-22603 Hamburg, Germany

Abstract

The basic concepts and predictions of the 'dynamical' GRV parton distributions for hadrons and photons are discussed. Comparisons of these predictions with recent experimental results, especially from HERA, are presented.

1. Introduction

In the conventional approach to the proton's parton structure, the perturbatively uncalculable quark and gluon input densities for the Altarelli-Parisi (AP) Q^2-evolution are fitted, at some resolution scale Q_0 well in the perturbative region, $Q_0^2 = 2 \ldots 5$ GeV^2, to an exhaustive set of DIS and related data. See [1, 2] for recent examples. This procedure is sufficient to fix the parton distributions at all perturbatively accessible scales for $x > x_{min}$, where x_{min} (> 0.01 for pre-HERA DIS data) denotes the minimal momentum fraction for which enough experimental results are available to constrain the fit. However, extrapolations to smaller x are notoriously unreliable [1, 3] in this framework. Hence this approach does not possess predictive power for the small-x region now accessible at HERA.

One can try to get more out of the AP formalism by assuming a wider range of validity towards small Q^2 for this perturbative twist-2 renormalization group evolution than in the conservative approach summarized above. A basic observation in this context is that the constraint imposed by the energy-momentum sum rule for the parton distributions becomes more important at smaller Q^2. The well-known maximal example is the purely dynamical generation of the gluon (g) and sea quark ($\bar{q}$) densities [4]. There it is assumed that the AP equations apply down to a very low scale μ_D, where the valence quark densities (which evolve separately and are constrained by the charge sum rules at small x) saturate the momentum sum rule and thus leave no room for non-vanishing sea and gluon inputs. Hence this approach completely predicts g, $\bar{q}\,(x, Q^2 > \mu_D^2)$ dynamically at all x. These predictions, however, are too steep in x as compared to experimental constraints [3]. Theoretical objections have also been raised [5].

In this talk we will give a brief summary of a less ambitious, but theoretically more sound approach, in which all parton densities are generated from intrinsic valence-like initial distributions at some low scale μ determined from large-x proton structure constraints. Usually the resulting distributions are (somewhat simplifying) also described as 'dynamical'. In fact, this procedure leads to rather unambiguous dynamical predictions for g and $\bar{q}$ at small x [6, 7, 8]. Moreover, the application of this concept to pions and photons allows for (approximate) predictions of g^π and g^γ also at large x [9, 10]. We will focus on these phenomenological predictions and their comparison to recent experimental results, most noteably from HERA. See [8] for a discussion of theoretical issues related to this approach.

* Talk given at the Workshop on Deep Inelastic Scattering and QCD, Paris, April 1995.

♯ On leave on absence from Sektion Physik, Universität München, D-80333 Munich, Germany

2. Partons in the proton

One place where the purely dynamical predictions are too small is fixed-target direct-photon (DP) production, $pp \to \gamma X$. This process probes the large-x gluon density, $x \gtrsim 0.3$. Thus the DP data enforce a substantially harder gluon distribution [3]. Together with the momentum sum rule constraint, these results lead to a valence-like form of $g(x, \mu^2)$, $g \sim u_v$, if a sufficiently small input scale μ is chosen. Since evolution from a sizeably smaller scale would need a physically unreasonable input (g harder than u_v), μ can be assumed to be the lowest scale down to which the perturbative AP equations may hold. The basic assumption is that μ can actually be reached perturbatively.

The most simple valence-like gluon and sea quark input ansatz has been employed to fix μ [6]:

$$xg(x, \mu^2) = Ax^a(1-x)^b, x\bar{q}(x, \mu^2) = A'x^{a'}(1-x)^{b'}. \quad (1)$$

The free parameters of (1) have been determined from fixed-target DIS and DP data, with the valence distributions u_v and d_v and the QCD scale parameter $\Lambda^{(4)} = 0.2$ GeV taken from a conventional fit. This procedure results in $g \sim u_v$ for $\mu \simeq 0.55$ GeV in next-to-leading order (NLO) perturbative QCD, corresponding to $\alpha_s(\mu^2)/\pi \simeq 0.2$ [6]. Obviously, the accuracy of this μ determination is limited by the accuracy of the large-x data used. An uncertainty of about 10% has been estimated in [7]. The complete set of initial distributions is shown in fig. 1, together with that one of the recent update [8] incorporating later large-x constraints. In this update, $\mu = 0.58$ GeV.

At large-x, $x > 10^{-2}$, this approach comes close to the conventional procedure if only the partons in the proton are considered. At small-x and $Q^2 \gg \mu^2$, however, the behaviour of the gluon and sea quark densities is due to the QCD dynamics here, since ambiguities from the initial distributions are suppressed by their valence-like form (small at small-x) and the long evolution distance. Hence the predictive power of the purely dynamical approach [4] is retained in this regime. The uncertainty of μ mentioned above leads to rather moderate an uncertainty of the small-x predictions amounting to, e.g., less than 20% (10%) at $x = 10^{-4}\,(10^{-3})$ for $Q^2 \gg \mu^2$ [7]. The dependence on the precise value of $\Lambda^{(4)}$ is also small, see [11].

These dynamical small-x predictions [6, 8] are compared with recently published HERA results on the structure function F_2^p (rather directly measuring the quark distributions) and on the gluon density (constrained by the observed scaling violations in F_2^p) in fig. 2 and fig. 3, respectively. Very recently, the HERA collaborations have extended their F_2 determination to lower Q^2 [17, 18], and the final small-Q^2 E665 data have been presented [19]. In fig. 4 the GRV predictions are also confronted to these results. Within their uncertainty indicated above, these (leading-twist) predictions quantitatively describe all present structure

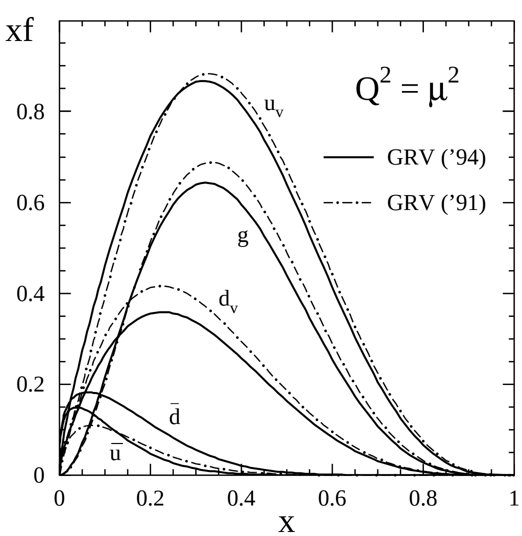

Figure 1. The NLO valence-like GRV input distributions. $\mu^2 = 0.30$ (0.34) GeV^2 for the '91 ('94) parametrizations [6, 8]. The strange sea $s = \bar{s}$ vanishes at $Q^2 = \mu^2$. $\bar{u} = \bar{d}$ in GRV ('91).

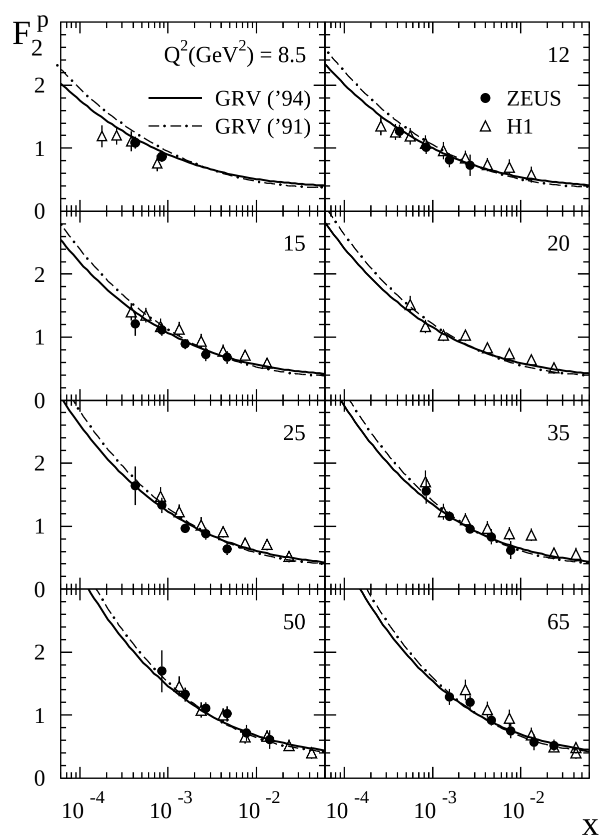

Figure 2. NLO dynamical small-x GRV predictions [6, 8] for F_2^p vs. recent HERA data [12, 13]. The charm contribution has been calculated using the NLO massive expressions of [14].

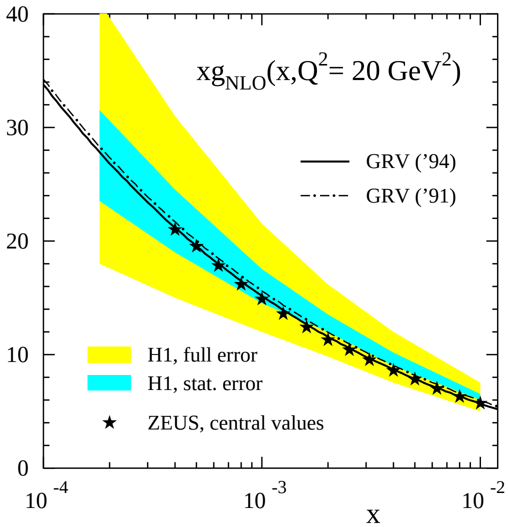

Figure 3. The dynamical predictions for the NLO gluon density at small-x [6, 8] as compared with constraints derived from F_2^p scaling violations at HERA [15, 16].

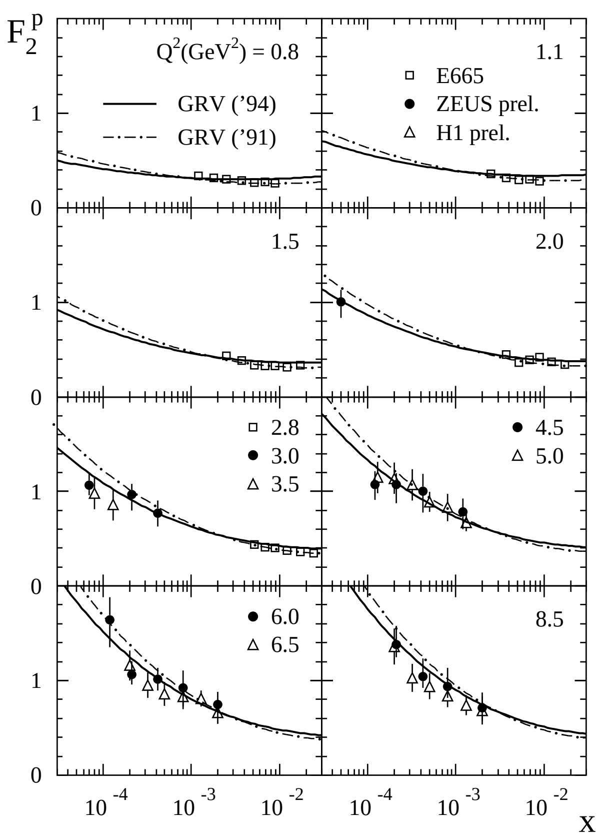

Figure 4. As fig. 2, but with the preliminary low-Q^2 HERA results [17, 18] and the final E665 data [19]. At $Q^2 > 2$ GeV^2, the curves have been calculated for the ZEUS Q^2-values.

function measurements at small-x down to $x < 10^{-4}$, including the transition from a rather flat behaviour at $Q^2 < 1$ GeV^2 to the steeply rising F_2 at high Q^2.

3. Partons in the pion

The parton distributions of the pion are experimentally much less constrained than those of the nucleon. Information on the valence density v^π (at $x \gtrsim 0.2$) and on the the gluon distribution g^π (at $x \gtrsim 0.3$) has been inferred from pionic lepton-pair and direct-photon production, respectively, see [20, 21]. Virtually nothing is known about the pionic sea quark density ξ^π.

Nevertheless, the available constraints allow for an additional test of the concept of valence-like low-scale input distributions. As discussed above, μ in (1) represents the lowest scale down to which the perturbative AP evolution is supposed to hold. Hence μ should not depend on the hadron under consideration and is taken over from the proton analysis. In view of the experimental situation summarized above, the most simple valence-like ansatz is appropriate here [9]:

$$g^\pi(x,\mu^2) = k\, v^\pi(x,\mu^2)\ ,\quad \xi^\pi(x,\mu^2) = 0\ . \qquad (2)$$

Since k is known from the momentum sum rule, (2) provides a parameter-free prediction of $g^\pi(x, Q^2 > \mu^2)$ once the valence distribution is fixed. In fig. 5 this prediction, using v^π of [20], is compared to the DP constraints and perfect agreement is found.

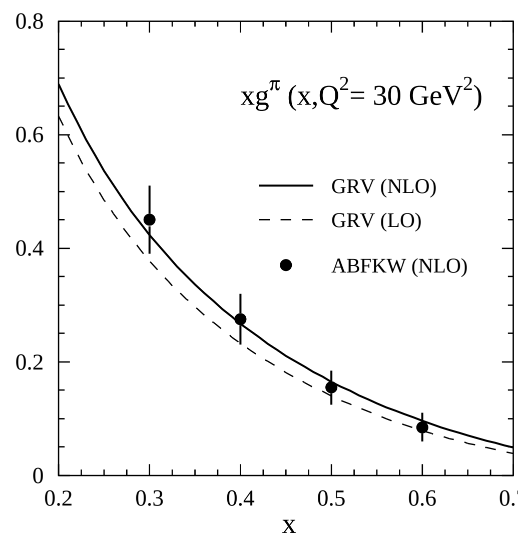

Figure 5. The NLO and LO GRV predictions for the gluon density of the pion [9] in comparison with the NLO error band obtained from $\pi p \to \gamma X$ (ABFKW) [20].

4. Partons in the photon

The quark content q^γ of the photon has been measured (with so far rather limited precision) at e^+e^- colliders via the photon structure function F_2^γ for $x \gtrsim 0.05$. The gluon density g^γ is virtually unconstrained by these data, see [22]. A usual assumption is that at some low

resolution scale the partonic structure of the photon is very closely related to those of the vector mesons (vector meson dominance, VMD). However, it is well known that for input scales $Q_0^2 \geq 1$ GeV^2 a pure VMD initial condition for the photon's modified AP equations is not sufficient to describe the F_2^γ data at larger Q^2.

In the present approach, it is very natural to impose a pure VMD input at the scale μ [10]:

$$(q,g)^\gamma(x,\mu^2) = \kappa \frac{4\pi\alpha}{f_\rho^2}(q,g)^{\pi^0}(x,\mu^2) \ . \qquad (3)$$

Here $f_\rho^2/(4\pi) = 2.2$ is the $\rho\gamma$-coupling and the (GRV) parton densities of the pion have been used instead of the experimentally unknown ρ distributions. κ accounts in the most simple way for the higher-mass vector mesons, one expects $1 \lesssim \kappa \lesssim 2$. In NLO, (3) has been implemented in the DIS_γ factorization scheme, since in the photon case the $\overline{\mathrm{MS}}$ scheme is not suited for physically motivated input shapes [23]. κ has been determined from the available F_2^γ data, resulting in a good fit for $\kappa = 1.6$ in NLO [10].

Therefore, a pure VMD input at μ is in fact successful, and one obtains an approximate VMD-based prediction of g^γ at large-x in addition to the typical dynamical small-x predictions. Besides from the treatment of the higher-mass vector mesons and from the $\rho \to \pi$ substitution in (3), uncertainties of these predictions arise from the uncertainty of the pion's quark content: ξ^π is unknown, and the normalization of v^π is uncertain by about 20% even in the large-x region [20, 21]. A larger v^π (as in [21]) would obviously lead, via the fit of κ in (3), to a corresponding decrease of g^γ. Fig. 6 shows the agreement of this approximate prediction with a first HERA extraction of g^γ.

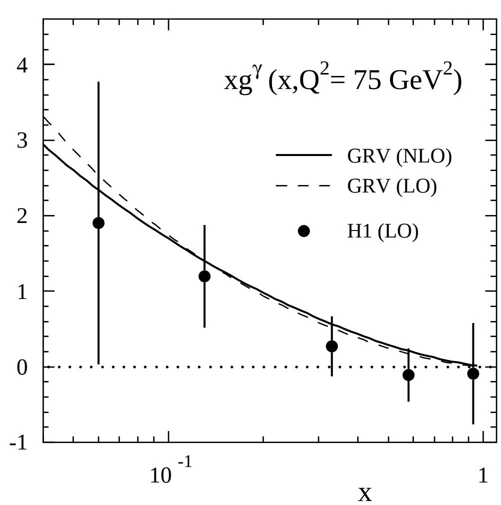

Figure 6. The NLO and LO GRV prediction for the photon's gluon density [10] compared with HERA (H1) results from a LO analysis of 2-jet photoproduction data [24].

5. Conclusions

Valence-like initial distributions at a low resolution scale $\mu \lesssim 0.6$ GeV for $\Lambda^{(4)} = 0.2$ GeV allow for a coherent description of the parton structure of hadrons and photons. Although this approach is not predictive at large-x in the proton case, it leads to an essentially parameter-free prediction of the pion's gluon density in this x-region and an (approximate) VMD-based prediction for the gluon content of the photon. The approach exhibits its full predictive power at small-x, where the gluon and sea quark densities are generated dynamically. Present data are in very good agreement with all these predictions.

Acknowledgements

It is a pleasure to thank M. Glück and E. Reya for a fruitful collaboration. I am grateful to S. Riemersma for making available the NLO F_2^{charm} computer code of [14]. This work was supported by the German Federal Ministry for Research and Technology under contract No. 05 6MU93P.

References

[1] A.D. Martin, W.J. Stirling and R.G. Roberts, Phys. Rev. **D50** (1994) 6734; Rutherford Appleton Lab RAL-95-021.
[2] H.L. Lai et al., CTEQ coll., Phys. Rev. **D51** (1995) 4763.
[3] M. Glück, E. Reya and A. Vogt, Z. Phys. **C48** (1990) 471; Nucl. Phys. B (Proc. Suppl.) **18C** (1990) 49.
[4] G. Parisi and R. Petronzio, Phys. Lett. **62B** (1976) 331; V.A. Novikov et al., JETP Lett. **24** (1976) 341; Ann. Phys. (N.Y.) **105** (1977) 276; M. Glück and E. Reya, Nucl. Phys. **B130** (1977) 76.
[5] S.J. Brodsky and I. Schmidt, Phys. Lett. **B234** (1990) 144.
[6] M. Glück, E. Reya and A. Vogt, Z. Phys. **C53** (1992) 127.
[7] M. Glück, E. Reya and A. Vogt, Phys. Lett. **B306** (1993) 391.
[8] M. Glück, E. Reya and A. Vogt, DESY 94-206, to appear in Z. Phys. **C**.
[9] M. Glück, E. Reya and A. Vogt, Z. Phys. **C53** (1992) 651.
[10] M. Glück, E. Reya and A. Vogt, Phys. Rev. **D46** (1992) 1973.
[11] A. Vogt, DESY 95-068, to appear in Phys. Lett. **B**.
[12] ZEUS coll., M. Derrick et al., Z. Phys. **C65** (1995) 379.
[13] H1 coll., T. Ahmed et al., DESY 95-006.
[14] S. Riemersma, J. Smith and W.L. van Neerven, Phys. Lett. **B347** (1995) 143.
[15] ZEUS coll., M. Derrick et al., Phys. Lett. **B345** (1995) 576.
[16] H1 coll., S. Aid et al, DESY 95-081.
[17] ZEUS coll., contributions to this workshop by B. Foster and M. Lancaster.
[18] H1 coll., contributions to this workshop by J. Dainton and G. Rädel.
[19] A.V. Kotwal, E665 coll., Fermilab-Conf-95/046-E, presented at the XXXth Rencontres de Moriond, March 1995.
[20] P. Aurenche et al., Phys. Lett. **B233** (1989) 517.
[21] P.J. Sutton et al., Phys. Rev. **D45** (1992) 2349.
[22] A. Vogt, Proceedings of the Workshop on Two-Photon Physics at LEP and HERA, Lund, May 1994, eds. G. Jarlskog and L. Jönsson (Lund Univ., 1994), p. 141.
[23] M. Glück, E. Reya and A. Vogt, Phys. Rev. **D45** (1992) 3986.
[24] H1 coll., T. Ahmed et al., DESY 95-062.